

APPLICATION FOR UNITED STATES LETTERS PATENT

FOR

A 1P1N 2T GAIN CELL

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Express Mail Label No.: EV310166067US

Date of Deposit: December 30, 2003

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BACKGROUND

The use of embedded memories has become increasingly common in the design of integrated circuits such as microprocessors. A 2T (e.g., two-transistor) gain cell is one type of embedded memory which is commonly used in dynamic random access memory (DRAM). In a 2T cell there is typically one transistor to control read operations and one transistor to control write operations.

The amount of gate leakage current in a memory cell, such as a 2T gain cell, can determine how often a memory cell will need to be refreshed, and is often used as a measure of memory cell quality. When a memory cell is in the middle of a refresh cycle for example, devices such as a microprocessor that wish to access the memory cell are required to wait until the refresh process is complete, thereby impacting system performance.

In the past, the amount of leakage current existing in memory cells was negligible due to relatively thick oxide layers within the transistors of the memory cells. However, as oxide layers continue to become thinner and thinner due to technology scaling for example, the measure of leakage current within memory cell devices has become an increasingly important design limitation.

BRIEF DESCRIPTION OF DRAWINGS

The present invention will be described by way of exemplary embodiments, but not limitations, illustrated in the accompanying drawings in which like references denote similar elements, and in which:

5 Figure 1 illustrates a schematic diagram of a conventional two-transistor gain cell utilizing two n-channel metal oxide semiconductor (NMOS) devices;

 Figure 2 illustrates an example graph of the voltage level at storage node Ns 114 of memory cell 100 as a function of time;

 Figure 3 illustrates a schematic diagram of a novel two-transistor gain cell
10 arrangement utilizing one NMOS device and one PMOS device, in accordance with one embodiment of the present invention;

 Figure 4 illustrates an example graph of the voltage level at the storage node Ns 314 of memory cell 300 as a function of time;

 Figure 5 illustrates a schematic diagram of a two-transistor gain cell utilizing
15 one NMOS device and one PMOS device in accordance with an alternative embodiment of the present invention; and

 Figure 6 illustrates one of many possible systems in which a two-transistor DRAM memory cell may be used.

DETAILED DESCRIPTION OF ILLUSTRATED EMBODIMENTS

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of embodiments of the present invention. However, those skilled in the art will understand that such embodiments may be
5 practiced without these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail.

Although various discrete operations will be described herein, the mere order of description should not be construed as to imply that these operations are necessarily performed in the order they are presented.

10 Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily
15 all referring to the same embodiment or invention. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments. Lastly, the terms “comprising”, “including”, “having”, and the like, as used in the present application, are intended to be synonymous.

Figure 1 illustrates a schematic diagram of a conventional 2T gain cell
20 utilizing two n-channel metal oxide semiconductor (NMOS) devices. As shown, memory cell 100 includes a first NMOS device TW 105 having a first controlled node 106, a second controlled node 107, and a gate 108. Since MOS transistors are symmetrical, the designation of a source or drain terminal is somewhat arbitrary as

determined by the voltage applied to the device. Accordingly, the term “controlled node”, as used herein, may refer to either a source or drain terminal within a MOS transistor (e.g., NMOS and PMOS). Memory cell 100 further includes a second NMOS device TR 110 having a first controlled node 111, a second controlled node 112, and a gate 113. As shown, the gate 113 of TR 110 may be coupled to the second controlled node 107 of TW 105 defining a charge storage node (Ns) 114 therebetween. The charge storage node Ns 114 may have a capacitance equal to the sum of the parasitic capacitance of the second controlled node 107 of TW 105 and the parasitic capacitance of the gate 113 of TR 110.

In Figure 1, TR 105 is configured as a write device and is coupled to a write word-line (WWL) 130 and a write bit-line (WBL) 120. In contrast, TR 110 is configured as a read device and is coupled to a read word-line (RWL) 125 and a read bit-line (RBL) 115. In memory cell 100, a write operation may be performed when WWL 130 is transitioned to a logic high state causing write device TW 105 to turn-on. In order for a “0” to be written into the memory cell, WBL 120 may be set to a logic low state causing the cell storage node Ns 114 to be pulled to ground. In order for a “1” to be written into memory cell 100, WBL 120 may be set to a logic high state causing Ns 114 to maintain a voltage ($V_{HIGH} - V_t$), where V_{HIGH} is the voltage of WBL (V_{WBL}) and V_t is the threshold voltage of write device TW 105. At the end of a write operation, WWL 130 may be transitioned to a logic low state causing write device TW 105 to be effectively turned OFF. Throughout the write operation, both RWL 125 and RBL 115 may be held at V_{HIGH} causing read device TR 110 to be similarly turned off.

In memory cell 100, a read operation may start with RWL 125 being pulled to a lower voltage from V_{HIGH}, causing read device TR 110 to be turned on. The read current strongly depends on the gate-to-source voltage ($V_{NS} - V_{RWL}$) of the read device TR 110. For example, a larger current may be drawn by read device TR 110 from RBL 115 to RWL 125 when a "1" is stored in the memory cell 100 since V_{NS} will be higher than if a "0" is stored. Accordingly, the voltage at RBL 115 may fall faster when a "1" is stored in the cell than when a "0" is stored. A sense amplifier (not shown) coupled to RBL 115 is able to detect whether a "1" or a "0" is stored in the memory cell (e.g. as determined by V_{NS}) using well-known sensing methods, such as by comparing RBL 115 to a reference bit-line.

When memory cell 100 is not selected to perform read or write operation, it is considered to be in a hold state. In memory cell 100, such a hold state occurs when WWL 130 is low, RWL 125 and RBL 115 are high, and WBL 120 is either low or high. In such a hold state, both read device TR 110 and write device TW 105 are turned off and the voltage stored at Ns 114 may be retained for an amount of time equal to the retention time, which is limited by the amount of leakage current in the device.

As technology scales, and thickness of the oxide layer(s) used in such read and write devices becomes smaller, the more significant of a role the gate leakage of such devices plays. In particular, as the oxide layer thickness in a MOS device decreases, the leakage current between the gate and the two edges (e.g. controlled nodes) of the MOS device, as well as the leakage current between the gate and the substrate of the device can become significant.

In memory cell 100 of Figure 1 for example, the main gate leakage components are two edge leakage currents (at controlled nodes 111 and 112) in read device TR 110, and one edge leakage current (at controlled node 106) in write device TW 105. More specifically, since WWL 130 is at a logic low state and RWL 125 and RBL 115 are each at a logic high state, the voltage at Ns 114 (V_{NS}) gradually tends to settle to an intermediate voltage (V_{FINAL}) due to gate leakage. Unfortunately, however, in conventional two-transistor memory cells such as memory cell 100, V_{FINAL} is often approximately $V_{CC}/2$ resulting in relatively small retention times.

Figure 2 illustrates an example graph of the voltage level at storage node Ns 114 of conventional memory cell 100 as a function of time. As shown in Figure 2, after a "0" is written into a memory cell, such as memory cell 100, V_{NS} is pulled up by the gate leakage at TR 110 eventually stopping at V_{FINAL} where the leakage components are balanced. When a "1" is written into memory cell 100, V_{NS} is pulled down by the leakage component at TW 105 likewise causing V_{NS} to converge to V_{FINAL} . Thus, unless conventional memory cells, such as memory cell 100, are recharged in an amount of time that is less than the retention time (T_{RET}), the datum stored within such memory cells will typically collapse. The retention time T_{RET} refers to the time when the voltage difference of "1" and "0" collapses to certain 'delta V', that can be still sensed correctly. Retention time is an important performance measure of DRAM memory circuits as it determines how often cells need to be refreshed. Unfortunately, conventional 2T gain cells (such as memory

cell 100 of Figure 1 in which two NMOS transistors are used) will continue to exhibit shorter and shorter retention times as technology continues to scale down.

Figure 3 illustrates a schematic diagram of a 2T gain cell utilizing one NMOS device and one PMOS device in accordance with one embodiment of the present invention. In contrast to memory cell 100 of Figure 1, memory cell 300 of Figure 3 includes PMOS device TW 305 in place of NMOS device TW 105 to facilitate decreased gate leakage current and increased retention time within memory cell 300. As with memory cell 100, memory cell 300 includes WWL 130, RWL 125, WBL 120, and RBL 115. In one embodiment, PMOS device TW 305 may be coupled to WWL 130, WBL 120, and NMOS device TR 110 as shown. More specifically, controlled node 306 of PMOS device TW 305 may be coupled to WBL 120, and gate 308 may be coupled to WWL 130. Furthermore, controlled node 307 may be coupled to gate 113 of NMOS device TR 110 forming charge storage node Ns 314 there between.

The operation of memory cell 300 is similar to that of the conventional 2T memory cell 100 of Figure 1, except that WWL 130 is transitioned to a logic low state in order to turn on write device TW 305 in a write operation and is otherwise held at V_{HIGH} . For example, In order for a "0" to be written into the memory cell, WBL 120 is set to a logic low state and the cell storage node Ns 314 is pulled to V_t , where V_t is the threshold voltage of write device TW 305. In order for a "1" to be written into memory cell 300, WBL 120 is set to a logic high state causing Ns 314 to maintain a voltage V_{HIGH} , where V_{HIGH} is the voltage of WBL (V_{WBL}). At the end of a write operation, WWL 130 is transitioned to a logic high state causing write

device TW 305 to be effectively turned OFF. Throughout the write operation, read device TR 110 is similarly turned OFF as both RWL 125 and RBL 115 are set at V_{HIGH} . As a result, the storage node Ns 314 of memory cell 300 converges to V_{FINAL} after a write operation, where $V_{FINAL} = V_{HIGH}$, since WWL 130, RWL 125
5 and RBL 115 are held at V_{HIGH} .

Figure 4 illustrates an example graph of the voltage level as a function of time at the storage node Ns 314 of memory cell 300 of Figure 3. After a "0" is written into memory cell 300, V_{NS} is pulled up by the gate leakage at TR 110 and eventually stops at V_{FINAL} where the leakage components are zero. Similarly, when a "1" is
10 written into memory cell 300, V_{NS} remains at V_{HIGH} . Since V_{final} approaches V_{high} , the gate leakage decays rapidly and the time it takes V_{NS} to converge to V_{final} is longer than the scenario described with respect to Figure 1. Accordingly, by replacing one NMOS device of a two-transistor memory cell with a PMOS device, it is possible to increase retention time of the memory cell, thereby decreasing the
15 number of time the memory cell needs to be refreshed.

Furthermore, the behavior of the edge leakage current for the MOS devices of memory cell 300 is also different. When V_{NS} starts from V_{LOW} and collapses to V_{HIGH} , the voltage level difference between V_{NS} and V_{HIGH} also decreases. Thus, all three leakage current components act to decrease themselves as the collapse
20 continues, which in turn slows down the collapsing process. The closer V_{NS} gets to V_{HIGH} , the smaller the leakage current becomes (for all three edge leakage components), and hence the slower V_{NS} increases. Thus, the retention time for a memory cell, containing one NMOS device and one PMOS device, such as memory

cell 300, can be extended beyond that of conventional 2T memory cells, as e.g., illustrated in Figure 1.

Figure 5 illustrates a schematic diagram of a 2T gain cell utilizing one NMOS device and one PMOS device in accordance with an alternative embodiment of the present invention. In memory cell 500 of Figure 5, the PMOS device 510 is configured as a read device while the NMOS device 505 is configured as a write device. In particular, NMOS device TW 505 may be coupled to WWL 130, WBL 120, and PMOS device TR 510, while PMOS device TR 510 may be coupled to RWL 125, RBL 115, and NMOS device TW 505 as shown.

In memory cell 500, WWL130, RWL 125, and RBL 115 may be held at a logic low state in order for a datum to be stored within charge storage node Ns 514. In order to perform a write operation, WWL 130 may be transitioned to a logic high state causing write device TW 505 to turn-on. In order for a "0" to be written into the memory cell, WBL 120 may be set to a logic low state causing the cell storage node Ns 514 to be pulled to ground. In order for a "1" to be written into memory cell 500, WBL 120 may be set to a logic high state causing Ns 514 to maintain a voltage ($V_{HIGH} - V_t$), where V_{HIGH} is the voltage of WBL (V_{WBL}) and V_t is the threshold voltage of write device TW 505. At the end of a write operation, WWL 130 may be transitioned back to a logic low state causing write device TW 505 to be effectively turned OFF. Throughout the write operation, read device TR 510 is similarly turned OFF as both RWL 125 and RBL 115 are set at logic low state.

Figure 6 illustrates one of many possible systems in which a two-transistor DRAM memory cell (such as memory cell 300 or 500) equipped with an NMOS

device and a PMOS device in accordance with one embodiment of the invention may be used. In one embodiment, memory cell 300 may form part of a memory array such as a cache memory implemented in an integrated circuit (IC) 602 of system 600. In one embodiment, IC 602 may be a microprocessor. In alternate
5 embodiments, IC 602 may be an application specific IC (ASIC).

 In the illustrated embodiment, system 600 also includes a main memory 608, a graphics processor 610, a mass storage device 612 and an input/output module 614 coupled to each other by way of a communication channel 616. However, system 600 may include additional or fewer components than those illustrated
10 without departing from the spirit and scope of the invention. Examples of the memory 608 include but are not limited static random access memory (SRAM) and dynamic random access memory (DRAM). Examples of the mass storage device 612 include but are not limited to a hard disk drive, a compact disk drive (CD), a digital versatile disk driver (DVD), and so forth. Examples of the input/output
15 modules 614 include but are not limited to a keyboard, cursor control devices, a display, a network interface, and so forth. Examples of the communication channel 616 include but are not limited to a wired and/or wireless communication channel such as a peripheral control interface (PCI) bus, an Industry Standard Architecture (ISA) bus, and so forth. In various embodiments, the system 600 may be a wireless
20 mobile phone, a personal digital assistant, a pocket PC, a tablet PC, a notebook PC, a desktop computer, a set-top box, an entertainment unit, a DVD player, and a server.

While the present invention has been described in terms of the above-illustrated embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The present invention can be practiced with modification and alteration within the spirit and scope of the appended claims.

- 5 Thus, the description is to be regarded as illustrative instead of restrictive on the present invention.